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Analysis of Team Communications to Understand Cognitive Processes used during Team Collaboration

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Susan G. Hutchins and Tony Kendall
Naval Postgraduate School, Monterey, CA

POC: Susan G. Hutchins
Graduate School of Operational
and Information Sciences
1411 Cunningham Rd.
Naval Postgraduate School
Monterey, CA 93943
831.656.3768
shutchins@nps.edu

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Analysis of Team Communications to Understand Cognitive Processes used during Team Collaboration

Susan G. Hutchins and Tony Kendall

Macrocognition describes the way cognition occurs in naturalistic, or real-world, decision-making events and comprises the mental activities that must be successfully accomplished to perform a task or achieve a goal. The emphasis in macrocognition is on the cognitive functions performed during collaborative team problem solving and how teams can perform them. For this research we employed an empirical process for evaluating a model of team collaboration by analyzing and coding transcripts or chat logs that transpired during several real-world problem-solving events. Team communications that transpired when teams collaborated to solve complex problem-solving tasks from two decision-making domains were analyzed and coded using the definitions of the macrocognitive processes in the model of team collaboration. Two coders coded each set of data and then reviewed their coding with one of the authors and discussed any differences in interpreting the definitions. Kappa Cohen, an inter-rater reliability score, indicated high levels of agreement between coders for both sets of data. Consistent with our previous research we found that problem solving by these teams comprised a series of decisions. That is, decisions were made iteratively throughout the entire problem situation as opposed to problem solving culminating in team members agreeing on one big final decision.

Macrocognition is an emerging field within the area of cognitive engineering that describes the way cognition occurs in naturalistic, or real-world, decision-making events (Cacciabue & Hollnagell, 1995). When studying macrocognition, the focus is on the mental activities that must be successfully accomplished to perform a task or achieve a goal (Klein, Ross, Moon, Klein, Hoffman, & Hollnagel, 2003). These cognitive functions are generally performed during collaborative team problem solving, where the emphasis is on building new knowledge. Macrocognition is differentiated from microcognition in several ways. Microcognition places an emphasis on experimental control of tasks and theoretical accounts of specific phenomena while macrocognition emphasizes cognition and performance under actual working conditions. Macrocognitive phenomena generally occur over longer time periods, involve unstructured tasks, and do not focus on the “basic” cognitive functions of microcognition (e.g., attention and memory).

Macrocognition encompasses cognitive processes involved in detecting problems, developing and sharing situation awareness, generating options, using analogues, mentally simulating courses of action, planning and re-planning, maintaining vigilance, and assessing risk (Klein, 2001). Several groups of researchers maintain that research on macrocognition is needed to better understand the cognitive functions employed by teams when they collaborate to solve challenging, information-rich, time-compressed problems (Klein et al, 2003; Fiore, Smith & Letsky, 2008; Letsky & Warner, 2008). This understanding can then be applied to improve the cognitive engineering of future systems.

One goal for studying macrocognition is to understand the complexity entailed in inter- and intra-individual cognition. For the research reported in this paper, we focus on cognition in problem-solving teams who collaborate while performing real-world tasks, in line with the view of macrocognition that seeks to describe cognitive work as it naturally occurs (Klein et al, 2003). We seek to better understand how cognition emerges in problem-solving teams engaging in tasks involving short-term situations which require rapid action to be taken towards specific mission goals. Macrocognition is defined, for this research, as the internalized and externalized high-level mental processes employed by teams to create new knowledge during complex, one-of-a kind, collaborative problem solving (Burke, 2007; Letsky, Warner, Fiore, Rosen, Salas, 2007). High-level mental processes refer to the cognitive processes involved in combining, visualizing, and aggregating information to resolve ambiguity in support of the discovery of new knowledge and relationships.

Internalized processes, that is, processes occurring inside the head, are those higher-level mental [cognitive] processes that are not expressed externally (e.g., writing, speaking, gesture), and can only be measured indirectly via qualitative metrics (e.g., questionnaires, cognitive mapping, think aloud protocols, multi-dimensional scaling, etc.), or surrogate quantitative metrics (e.g., pupil size, galvanic skin response). These processes can become either fully or partially externalized when they are expressed in a form that relates to other individual's reference/ interpretation systems (e.g., language, icons, gestures, boundary objects (Letsky et al., 2007).

Externalized processes (processes occurring outside the head) are those higher-level mental [cognitive] processes that occur at the individual or team level, and which are associated only with actions that are observable and measureable in a consistent, reliable, repeatable manner, or through the conventions of the subject domain have standardized meanings (Letsky et al, 2007).

The framework of collaborative problem solving developed as part of the Office of Naval Research Collaboration and Knowledge Integration (CKI) Program (Letsky, Warner, Fiore, & Salas, 2007; Warner, Letsky, & Cowen, 2005) provides the conceptual foundation for this research. The emphasis on macrocognition in teams was initiated as part of a larger issue of how to understand and facilitate complex, collaborative activity – specifically in quick-response ad hoc teams. Both commercial and military communities are evolving in response to an increased reliance on socio-technical systems, globalization, and ubiquitous information accessibility; a development which leads to changes in the dynamics of team activity (Letsky & Warner, 2008). The CKI program seeks to develop a better understanding of internalized, non-quantifiable, mental processes at work as teams collect, filter, process and share information for problem-solving purposes.

The objective of the CKI program is to respond to emerging needs in both the military and business environments to better understand and improve the effectiveness of team decision making in complex, data-rich situations. As part of this effort, a model of team collaboration was developed that emphasizes the cognitive aspects of team collaboration and includes the major human decision-making processes used during team collaboration (Warner, Letsky & Cowen, 2005). The long-range program objective is to develop cognitive science-based tools, models, computational methods, and human-agent interfaces to help attain common situation awareness among distributed team members, engaged in asynchronous, quick-response collaboration for issue resolution, or decision making.

The goal for the research reported here is to understand the role of cognition in teams who are collaborating to solve challenging, dynamic, experienced-based, knowledge intensive, ambiguous problems. Our objectives are (1) to empirically evaluate a model of team collaboration (Letsky et al., 2007) by analyzing the macrocognitive processes used by teams during real-world complex decision-making events, (2) to refine the model as necessary, and (3) as a result of our analysis to develop a better understanding of the cognitive processes involved in team collaboration.

Team Collaboration

Many definitions of collaboration are found in the different bodies of research literature (see Wood and Gray, 1991). At the most fundamental level, collaboration refers to the joint effort of two or more agents to achieve a common goal where collaborating members construct judgments and then act on these judgments (Nosek, 2004). A definition more aligned with the research reported here states that collaboration occurs "when a group of autonomous stakeholders of a problem domain engage in an interactive process, using shared rules, norms, and structures, to act or decide on issues related to that domain" (Wood & Gray, 1991, p.11). This interactive process is performed in a collaborative team environment, with *collaborative* defined as the "cognitive aspects of joint analysis or problem solving for the purpose of attaining shared understanding sufficient to achieve situational awareness for decision making or creation of a product" (Letsky & Warner, 2008, p. 4). Collaboration provides increased information processing capacity where more minds are enlisted to handle complex problems (Hocevar, Thomas, & Jansen, 2006). Team members offer several perspectives on an issue for generating, choosing, and implementing action plans. A collaborative approach also ensures greater flexibility and innovation in situations where human judgment and experience are leveraged (Hocevar, et al, 2006.)

In this paper, we examine team collaboration in three distinct task domains involving two tasks we label "execution" tasks and one planning task: an air operations center exercise that involved time-sensitive targeting, the Federal Aviation Administration (FAA) collaborating with the Northeast Air Defense Sector (NEADS) on Sept 11, 2001, and a planning task for UAV utilization.

Decision Making

A decision can be defined as a "mental event that occurs at a singular point in time…that leads *immediately* or *directly to action*" [italics added] (Hoffman & Yates, 2005, p. 77). From this perspective, a decision is a commitment to a course of action. Other researchers view decision making as a macrocognitive process that both supports and is supported by deciding (Klein, Ross, Moon, Klein, Hoffman, & Hollnagel, 2003). A complex problem-solving situation typically entails many decisions. These decisions include implementing actions in response to prior conditions or to the existing situation. As a situation unfolds, it will likely present new events requiring a decision.

Dynamic Decision-Making Tasks

Dynamic decision-making tasks, such as the decision domains investigated for this research, are characterized by situations where: (1) A series of decisions is needed, that is, the problem-

solving event comprises many decisions to effectively deal with the problem as it unfolds. (2) Decisions are not independent because current decisions are constrained by earlier decisions, and, in turn constrain later ones. (3) The problem state changes during the decision process both autonomously – as the situation continues to unfold, and as a consequence of the decision-maker's actions. (4) Decisions are made in real time (Brehmer, 1992). It is necessary for the practitioner to consider how the current decision will solve the immediate problem, as well as how it will impact future aspects of the overall problem-solving task. More importantly, it is not sufficient to make correct decisions "in the correct order, they also need to be made at the correct moment in time" (Brehmer, 1992, p. 16). Dynamic decision making situations are inherently stressful in part because the decision maker cannot control when these critical decisions have to be made.

Dynamic decision making tasks are found across the spectrum of problem solving domains, including process control plants, patient management in hospitals, managing a business, and fighting a battle. Two of the tasks we examined were dynamic decision-making tasks, and one was a planning task. Our objective was to compare the team collaboration that is entailed in a planning task versus a dynamic decision-making or execution task to see if differences exist in the macrocognitive processes used by teams engaged in two different types of tasks, that is, planning versus execution.

Implementing the decision often shapes both the problem as well as the cognitive process involved in decision making. An example from air warfare would be where the tactical action officer (TAO) recommended issuing a verbal warning to an aircraft in the vicinity of the ship in an effort to obtain additional information on the possible intent of the aircraft. However, in one particular case, the more experienced commanding officer (CO) negated that recommended action because, as he put it, "we don't want to do that because, he may not even see us here in this confined area and that may just serve as a flag to the pilot – there is a U.S. Navy warship." In this case the CO was thinking ahead to how a decision would impact the future situation. This represents an example of anticipatory thinking (Klein, Snowden, & Pin, 2007).

By implementing a decision, and obtaining feedback on its results, the operator has changed the problem. For example, taking an action against an inbound aircraft, during an air warfare scenario aboard a US Navy ship, and observing that aircraft's response, or lack of response to that action, will recast the problem, or change the practitioner's mental model of that task, in terms of determining the intent of the aircraft. In a similar vein, during a Coast Guard maritime interdiction operation (MIO), collecting new information by obtaining the results of analysis of radiological data will move the boarding officer's assessment of the type of cargo further along toward a resolution of the problem (that is, identifying the type of cargo and what type of response is required).

A team can be defined as a "small group of people with complementary skills who are committed to a common purpose, performance goals, and approach for which they hold themselves mutually accountable" (Katzenbach & Smith, 1993, p. 45).

Model of Team Collaboration

In this paper we report on research conducted to empirically evaluate and, if necessary, refine a model of team collaboration developed by Fiore, Smith-Jentsch, Salas, Warner, & Letsky (in

press), depicted in Figure 1. The model was developed to describe the dimensions of macrocognition where the emphasis is to describe these processes in a measurement framework and includes collaborative stages that the team goes through during the problem-solving task, the cognitive processes used by the team, and final outputs, such as the selected course of action. The focus of the collaboration model is on developing new knowledge among the team members.

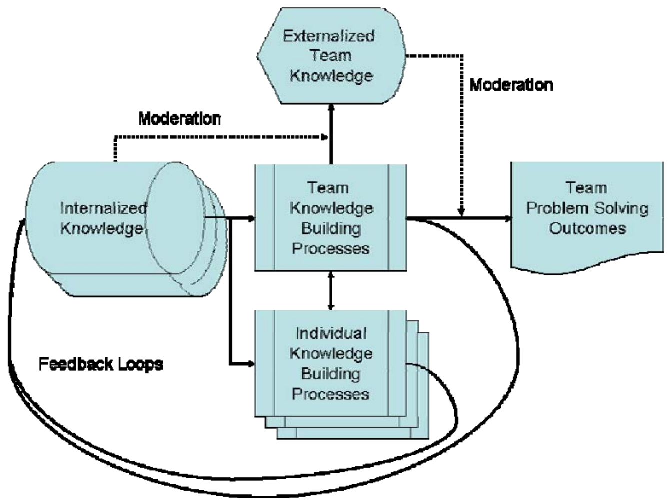

Figure 1. Model of Team Collaboration **(from Fiore, et al, in press).**

Table 1 includes descriptions of the macrocognitive processes included in this model of team collaboration, developed by Fiore, et al (in press). Examples of chat log entries from an air operations center scenario coded as macrocognitive processes included in the model of team collaboration are also included in Table 1. *Internalized team knowledge* refers to the collective current knowledge held in the individual minds of team members. *Individual knowledge building* refers to actions taken by individuals to build their own knowledge. *Team knowledge building* is a process that includes actions by teammates to disseminate information and transform information into actionable knowledge. *Externalized team knowledge* refers to the current knowledge overtly expressed to other team members through communication and/or artifacts during collaborative team problem solving. *Team problem solving outcomes* are assessments of the quality relative to a team's problem solving or plan.

METHOD

Definitions of the macrocognitive process categories developed by Fiore et al (in press) were used to code team members' communications. The first task domain we analyzed was the distributed team collaborative communications between two federal agencies: the team at the Federal Aviation Administration (FAA) and Northeast Air Defense Sector (NEADS), the regional headquarters for the North American Aerospace Defense Command (NORAD) responding to the events on Sept. 11, 2001. The second set of communications data was the Chat logs from an Air Force research event in the Air and Space Operations Center Dynamic Effects Cell. The third was the Chat logs from an experiment involving planning for unmanned autonomous vehicle (UAV) utilization. These domains were selected because they present the types of complex collaborative problem-solving scenarios the model seeks to explain. In the first two problem-solving tasks, developing and maintaining situation awareness was particularly difficult due to time pressure, high workload, incomplete or ambiguous information, and the knowledge-

intensive nature of the task. Moreover, many military tasks require several geographically separated personnel to quickly form a cohesive team, where the team must be able to effectively share and process data, information, and knowledge to facilitate rapid decision making.

Table 1. Macrocognitive Process Definitions and Examples from Air Operations Data.[1]

<table>
<tr><td colspan="2"><u>Stage I: Internalized Team Knowledge Process:</u> Refers to the collective knowledge held in the individual minds of team members. Internalized Team Knowledge is measured by eliciting it from individual team members using methods such as card sorting, concept mapping, paired comparison ratings, scenario probes.</td></tr>
<tr><td></td><td>Team Knowledge Similarity: Team knowledge similarity can involve the degree to which differing roles understand one another (e.g., how well a land/sea vehicle specialist understands a humanitarian specialist), or how well the team members' understand the critical goals and locations of important resources (shared situation awareness).
- No coded examples for AOC data</td></tr>
<tr><td></td><td>Team Knowledge Resources: Team members' collective understanding of responsibilities and resources associated with the task.
• I remember sketchy authentication codes
• Fighter aircraft #2 is out of position, looks like other strike assets are quicker
• He wouldn't request to return to base (RTB), he tells you he is RTB</td></tr>
<tr><td colspan="2"><u>Stage II: Individual Knowledge Building Process:</u> is a process which includes actions taken by individuals in order to build their own knowledge. These processes can take place inside the head (e.g., reading, mentally rotating objects) or may involve overt actions (e.g., accessing a screenshot).</td></tr>
<tr><td></td><td>Individual Information Gathering: Individual information gathering involves actions individuals engage in to add to their existing knowledge such as reading, asking questions, accessing displays, etc.
• What is the correct way to pass tasking to a predator to attack?
• Joint coordinating elements do you know the local threat/ risk in the area and do you have imagery of the locations?
• Any battle damage assessment reports/imagery post-strike for aircraft?</td></tr>
<tr><td></td><td>Individual Information Synthesis: Individual information synthesis involves comparing relationships among information, context, and artifacts to develop actionable knowledge.
• Reliable sources report a known country bomb component supplier is
• Awaiting a large shipment of explosives- It is suspected that a certain country uses this location as a storage facility for spent fuel.</td></tr>
<tr><td></td><td>Knowledge Object Development: Knowledge object development involves creation of cognitive artifacts that represent actionable knowledge for the task.
- No coded examples for AOC data</td></tr>
<tr><td colspan="2"><u>Stage III: Team Knowledge Building Process:</u> is a process which includes actions taken by teammates to disseminate information and to transform that information into actionable knowledge for team members.</td></tr>
<tr><td></td><td>Team Information Exchange: Team information exchange involves passing relevant information to the appropriate teammates at the appropriate times.
• Target priority coordinated, entered and pushed to joint time sensitive targeting manager
• The actual snatch and grab would be possibility for special operation force (SOF) but we would need intelligence assistance
• For your information, this area is now under SOF control. Reconnaissance aircraft to provide over watch, SOF is now in contact with aircraft</td></tr>
<tr><td></td><td>Team Knowledge Sharing: Team knowledge sharing involves explanations and interpretations shared between team members or with the team as a whole.
• Self defense applies for hostile acts from one country airspace to another</td></tr>
</table>

	• Enemy forces that employ ordnance, electronic attack or achieve a radar lock against friendly forces have committed a hostile act.
	Team Solution Option Generation: Team solution option generation describes offering potential solutions to a problem. • Awaiting radiological impact assessment on watershed if strike building. Second option in work is destroy local roads to prevent access in/out. • If we crater the runway and taxiways, we may be able to effectively stop the target. • To shorten timeline for tactical tomahawk we can launch to loiter. Will attempt to mitigate with weaponeering
	Team Evaluation and Negotiation of Alternatives: Team evaluation and negotiation of alternatives describes clarifying and discussing the pros and cons of potential solution options. • Just throwing this out there, but if you target the roadways, is there a chance you could spook them and they might fire off their missiles and run?
	Stage IV: Externalized Team Knowledge Process: Refers to facts, relationships, and concepts that have been explicitly agreed upon, or not openly challenged or disagreed upon, by factions of the team.
	Externalized Cue-strategy Associations: Externalized cue-strategy associations describe the team's collective agreement as to their task strategies and the situational cues that modify those strategies (and how). • The dynamic effects cell chief stated that if there is an erect launcher in a joint special operations area the "rule of engagement" is to kill it as soon as possible and if there is time to de-conflict with the teams • He mentioned tomahawk land attack missile (TLAM) wouldn't be de-conflicted either, but I dispute that logic. First, we wouldn't use a TLAM shot to kill a launcher • I don't think. Unless it was a last resort. • Can get special operation force team to location as additional resource if we elect to monitor the site for any potential leadership meetings that may occur later
	Pattern Recognition and Trend Analysis: Pattern recognition and trend analysis is the accuracy of the patterns or trends explicitly noted by members of a team that is either agreed upon or unchallenged by other team members. • Looks like this target may be similar to our first target with regards to unknown presence of radiological containers in facility. We would look at interdiction for containment to prevent travel to/fm that site, your thoughts on best plan/option.
	Uncertainty Resolution: Uncertainty resolution is the degree to which a team has collectively agreed upon the status of problem variables (e.g., hostile/friendly). • Tomahawk land attack missile most definitely have to be de-conflicted even for over flight of the joint special operations area unless direct otherwise by the Joint Force Commander.
	Stage V: Team Problem Solving Outcomes: Are assessments of quality relating to a team's problem solutions or plan.
	Quality of Plan: Quality of plan (problem solving solution) involves the degree to which the solution adopted by a problem solving team achieves a resolution to the problem (e.g., limit fatalities, limit destruction). - No coded examples for AOC data
	Efficiency of Planning Process: Efficiency of planning process describes the amount of time it takes a problem solving team to arrive at a successful resolution to a problem. - No coded examples for AOC data
	Efficiency of Plan Execution: Efficiency of plan execution describes the quality of the plan (e.g., number of lives saved) divided by the amount of resources used to accomplish this and the amount of time the plan takes to unfold. - No coded examples for AOC data

[1](Definitions of macrocognitive processes from Fiore et al., in press.)

Task Domain I: Federal Aviation Administration and Northeast Air Defense Sector

On Sept 11, 2001, defense of the U.S. airspace depended on close interaction between two federal agencies: the team at the Federal Aviation Administration (FAA) and Northeast Air Defense Sector (NEADS), the regional headquarters for the North American Aerospace Defense Command (NORAD). NEADS was the key command and control (C2) center for the U.S. military response during the terrorist attacks.

Task. The airspace of the continental US is monitored and protected by two main entities: the FAA, who is charged with navigating and controlling air traffic, and NORAD, who is charged with protecting the North American continent against air attack. In discharging its responsibilities, NORAD utilizes the airspace that is monitored by the FAA and must conduct their operations according to FAA regulations and with their active participation (Memorandum of understanding between FAA and NORAD, 1987). Thus, close coordination between the FAA and NORAD is required in order to maintain safety of the U.S. airspace.

Task Domain II: Air and Space Operations Center

A high-fidelity research event was conducted with Air Force personnel in the Air and Space Operations Center Dynamic Effects Cell. Dynamic targeting is a means by which coalition forces could possibly respond to the employment of improvised explosive devices (IEDs) and insurgent network leadership located within Afghanistan and Iraq. Due to their short time-sensitive nature, dynamic targets are normally vetted quickly and accurately through the targeting cycle. This process allows the Joint Force Air Component Commander (JFACC) to task available assets or reassign assets to engage and destroy known targets or other potential threats at a moment's notice. The limited time window available for target engagement and destruction means that coalition forces must be prepared to apply timely and accurate measures and counter-measures against the enemy.

Participants. Thirty-six key operational command and control military and civilian personnel from all services participated in the dynamic targeting exercise. Participants included personnel from the Air Force Warfare Center, Naval Strike Air Warfare Center, Special Operations Command, and United States Army (Air Force Research Laboratory Warfighter Readiness Division, 2008). The purpose was to assess tactics, techniques and procedures of operational command personnel performing kinetic and non-kinetic dynamic targeting in a highly asymmetric environment. The research event was a simulation of a 12-hour overnight shift in the dynamic effect cells of a typical air operations center (AOC). Communication between the various players was facilitated by the use of the Joint Automated Deep Operations Coordination System (JADOCS). JADOCS provides the warfighter with a timely, accurate, detailed battlespace view for planning, coordination, and execution of targets. It is a joint mission management software application that provides a suite of tools and interfaces for horizontal and vertical integration across battlespace functional areas (Raytheon Company, 2008). Communications were recorded across fourteen different chat room channels.

Task. Each of the operational players had varied access and responsibilities in the chat rooms used for the exercise. All players did not have access to every individual chat room; some key operational players were designated as room owner, active participant and/or observer. The allocation of assets to destroy key enemy leadership, suppression of enemy air defense systems,

convoy protection, close air support, and dynamic targeting are just a few of many ways by which the JFACC could use the assigned assets to render an adversary's method of attack ineffective and thereby minimize damage and coalition force and civilian casualties.

UAV Planning Task. Chat logs from a laboratory experiment were coded to provide a set of comparison data for a planning task. Three college students served as participants and were trained to engage in an unmanned aerial vehicle (UAV) simulation task where the task was to control their UAVs to obtain photos of assigned sites.

Coding of Team Communications

Communications between the FAA and NEADS teams were captured as audio recordings and subsequently transcribed. The audio from one of the primary communications channels used by the mission control commander (MCC), channel three – MCC Operations, was professionally transcribed. The resulting transcript provides a realistic example of an inter-agency collaborative team's response to a real-world emergency. Chat logs were used from the AOC exercise. Two graduate students coded the FAA/NEADS data and another pair of graduate students coded the AOC data to establish the reliability of our coding method. Subsequently, one of the authors coded the team communications in the chat log from the UAV planning experiment.

To determine the overall percentage of agreement between the two coders, the qualitative categorical statistic Cohen's Kappa was used. An additional code was created called the Extra Code Filler (ECF) which was used to indicate where one coder did not specify a separate code for an utterance. This was necessary to ensure that each coder assigned the exact same number of total codes in order to accurately calculate inter-rater reliability for the two coders, using Cohen's Kappa coefficient. Cohen's Kappa is the preferred statistic over the Chi-square statistic as kappa tests for agreement whereas Chi-square tests for association (Thomas, & Hersen, 2003). Cohen's Kappa accounts for and factors into the calculation that each coder may also agree by chance and not strictly because they chose the same selection option or code.

Communications were segmented into utterances; that is, elliptic or sentential constructions that referred to a distinct macrocognitive process. Each utterance was typically given a separate code; however, in some instances two utterances referred to the same cognitive process and were thus grouped under one code. One week prior to coding the FAA/NEADS and the AOC communications, two raters coded team communications data from a maritime interdiction operation exercise not included in the present data set. Raters discussed their respective coding with one of the authors to calibrate their use of the macrocognitive process categories. Following this training period they independently coded the FAA/NEADS transcript and the AOC Chat logs, subsequently reviewed their coding, calculated percent agreement, and resolved any differences in coding.

Inter-Rater Reliability. A pair of coders coded 2,493 and 2,278 utterances for the AOC and FAA/ NEADS data, respectively. Inter-rater agreement was 89.32% and 77%, for the AOC and FAA/ NEADS data, respectively. One coder coded the Chat log data for the UAV planning experiment.

RESULTS

Consistent with naturalistic decision making research (e.g., Fischer, Orasanu, & Montalvo, 1993; Klein, 1989; 1993; Mosier 1991; Orasanu & Connolly, 1993; Rasmussen, 1993) we found that

problem solving by the FAA and NEADS on Sept 11, 2001, the air operations center dynamic targeting scenario, and the UAV planning tasks comprised a series of decisions. The most significant finding is that a new macrocognitive process emerged during the coding process to account for team communications/ chat log entries where a team member made a Decision to Take Action (DTA): A team member either issued an order for a *course of action* (COA) or make a request for a team member to do something (that is, *request take action*). These two types of decisions are differentiated by the authority relationship between the speaker and receiver and the criticality of the action to be taken. A course of action is issued by a superior to a subordinate and the action to be implemented is more critical to the outcome of the scenario. Requesting a peer to take action involves a lower level type of decision in terms of the authority relationship, that is, peer-to-peer, and the less critical nature of the action to the outcome of the scenario.

Initially we did not anticipate team members involved in the UAV planning task to make the same types of decisions that required immediate action. However, although this was labeled a planning task it actually involved dynamic planning and re-planning while the participants were performing their tasks involved in navigating their UAV to obtain photos of designated sites. Decisions were made iteratively throughout the entire problem situation for the two tasks that we label “execution,” or dynamic decision making tasks as well as, to a lesser degree, for the dynamic UAV planning task. This UAV task also entailed execution of the task. The participants were engaged in “on-the-fly” planning based on directions from experimenters regarding which target to photograph next. This dynamic planning and execution task is distinct from a strictly planning task that culminates in team members agreeing on one big final decision (i.e., the plan) that is typical of a planning task. Based on these findings, we recommend the Fiore, Smith-Jentsch, Salas, Warner, and Letsky (in press) model of team collaboration be revised to include a new category: *Decision to take action.*

Table 2 presents the results of the coding of three tasks: two execution tasks and one planning task. Coders used additional categories to code the team communications for all three task domains; these include *administrative*, *miscellaneous* and *extra code filler (ECF).* While speech turns coded as administrative and miscellaneous contribute to effective, closed-loop communications they do not represent a cognitive process and were thus removed for this analysis. *Extra code filler* was a coding that was added to utterances where one coder had not coded an utterance and the other coded had to ensure an equal number of codes between the two coders.

Table 2 includes the percentages of the macrocognitive processes used when the administrative, miscellaneous, and ECF codes were removed from the calculations. Team Information Exchange, 51.5, 52.9, and 58 percent, respectively for the AOC, NORAD, and UAV data, and Individual Information Gathering, 21.9, 30.9, and 32.6 percent, for the AOC, NORAD, and UAV data, had the highest usage. In general, the large number of utterances/ chat log entries coded as Team *Information Exchange* and *Individual Information Gathering* indicate the huge emphasis on knowledge construction that is required at both the individual and team level for all three tasks. *Decision to Take Action* (a combination of *Course of Action* and *Request Take Action* codes) encompasses 10.3, 5.5, and 4.3 percent, respectively for the AOC, NORAD, and UAV data. Team Knowledge Sharing, the fourth highest used macrocognitive process was used 10.3, 3.7, and 4.3 percent, respectively.

Individual Knowledge Building involves actions taken at the intra-individual level for the purpose of building one’s own knowledge. This may involve reading task relevant content,

therefore, taking place in the head of the individual, or it may involve interactions with a system such as accessing a screenshot. These actions are hypothesized to involve *Individual Information Gathering*, *Individual Information Synthesis*, and *Knowledge Object Development*. These processes involve a number of activities ranging from reading, to question asking, to accessing displays. It is noteworthy that the vast majority of the communications coded as *Individual Information Gathering* involved instances of a team member asking a question. We interpret this as an indication of the high degree of ambiguity inherent in the three task domains reported on in this paper. For example, the AOC exercise placed team members in a time-compressed situation that required the operators to process a large amount of information from various intelligence sensors. Team members engaged in building their individual knowledge by asking lots of questions to continue to build on their existing knowledge and to maintain situation awareness in this dynamic environment. Similar results, where teams rely heavily on *Individual Information Gathering* and *Team Information Exchange* have been reported for several tasks including the Fire Department of New York responding o the events of Sept 11, 2001 (Hutchins & Kendall, 2008) and air warfare decision making in the combat information center of Navy ships (Hutchins & Kendall, in press).

Table 2. Percentage of Macrocognitive Process Codes for Three Tasks.

Code	Macrocognitive Process Categories	Percentage of Speech Turns		
Individual Knowledge Building		**AOC**	**NORAD**	**UAV Plan'g**
IIG	Individual Information Gathering	21.93	30.91	32.57
IIS	Individual Information Synthesis	3.63	1.74	0.75
KOB	Knowledge Object Development	0.00	0.00	0.00
Team Knowledge Building				
TIE	Team Information Exchange	51.45	52.87	58.00
TKS	Team Knowledge Sharing	10.33	3.74	4.29
TSOG	Team Solution Option Generation	0.90	3.07	0.00
TENA	Team Evaluation and Negotiation of Alternatives	0.49	0.00	0.00
TPPR	Team Process and Plan Regulation	0.00	0.00	0.00
Internalized Team Knowledge				
ITK	Team Knowledge Similarity	0.08	0.00	0.00
TKR	Team Knowledge Resources	0.16	0.00	0.00
IK	Inter-positional Knowledge (3)	0.06	0.20	0.00
ISA	Individual Situational Awareness (1)	0.00	1.67	0.00
Externalized Team Knowledge				
ECSA	Externalized Cue-Strategy Association	0.49	0.07	0.00
PRTA	Pattern Recognition and Trend Analysis	0.16	0.07	0.00
UR	Uncertainty Resolution	0.08	0.13	0.00
Problem Solving Outcomes				
QOP	Quality of Plan	0.00	0.00	0.00
EPP	Efficiency of Planning Process	0.00	0.00	0.00
EPE	Efficiency of Planning Execution	0.00	0.00	0.00
Decision to Take Action				
DTA	DTA (Issue Course of Action)	6.61	4.27	0.00
RTA	DTA (Request Take Action)	3.69	1.27	4.29

Inter-Rater Reliability

The high Kappa Cohen coefficient achieved by both pairs of coders indicates the two coder's agreement is substantial (Landis and Koch, 1977). The high inter-rater reliability kappa score indicates the macrocognitive process definitions used by the coders are objective. There is also evidence that most of the macrocognitive processes in this model of team collaboration are applicable to real world decision making domains.

Table 3 presents the results of the Kappa analysis, for the AOC data, in the form of a pivot table which compares coder 1 codes against coder 2 codes. Coder 1 codes are displayed in the columns and coder 2 codes are read across rows. Coder matches run diagonally through the pivot table, in the bolded cells, starting with Administrative 183, Miscellaneous 663, Team Information Exchange 1134, and so on. The pivot table also highlights which codes the coders disagreed upon. For example, under the *individual information gathering* (IIG) category, coder 1 and coder 2 had assigned a total of 537 and 526 IIG codes, respectively, to the data. However, both coders matched selections for 521 of the *individual information gathering* (IIG) codes. There were 16 and five instances, respectively, where coder 1 and coder 2 disagreed with the other coder. Reading down the column under IIG one sees that coder 1 had applied five *individual information gathering (IIG)* codes, one each for *team knowledge sharing (TKS), Course of Action (COA)*, *request take action (RTA)* and applied eight ECF codes. Similarly for coder 2, of the five codes that differed between the two coders for IIG, two each were coded as *ADMIN*, and *team information exchange (TIE)*, and one *team knowledge sharing (TKS)*.

In Table 3, the diagonal cells of the matrix indicate agreement between the coders whereas the values in the other cells indicate the difference between what each of the coders chose. As an example, in the pivot table, both raters agreed 1134 times on TIE, where coder 1 applied this code 1,192 times, to 58 additional utterances and coder 2 applied it 1187 times, or to 53 additional utterances.

When there was a disagreement on *Team Information Exchange* (TIE) or *Team Knowledge Sharing* (TKS) codes, the other code typically selected code was *Team Knowledge Sharing* and *Team Information Exchange* (respectively). Reading down the pivot table for category TIE, one sees the number of agreed upon *Team Information Exchange* codes is 1,134 and that coder 2 disagreed with coder 1 and selected *Team Knowledge Similarity* 17 times. Additionally, reading down *Team Knowledge Sharing* (TKS) category, both coders agreed 136 times but coder 2 disagreed and selected *Team Information Exchange* 24 times. The disagreement between TKS and TIE and the patterned alternative response of the other coder code indicates that there is some ambiguity in the measurement model definition for both of these macrocognitive processes. Furthermore, when coder 1 selected *Team Information Exchange* and *Team Knowledge Sharing*, coder 2 disagreed and selected the Extra Code Filler (ECF) code 20 and 39 times (respectively). This disagreement between coders and non selection of macrocognitive process definition indicates that the definitions for *Team Knowledge Sharing* and *Team Information Exchange* need to be refined to clarify remove any ambiguity.

Cases where there are large disagreements between two coders indicate the definitions for the macrocognitive process are not mutually exclusive and these definitions need to be refined. For example, the two coders agreed on 136 codes for team knowledge sharing (TKS) where coder 1 applied *TKS* a total of 209 times and coder 2 applied TKS 172 times. Looking across the row

labeled TKS one can see the other codes that were applied to utterances by coder 2 when coder 1 applied TKS. There were seventeen instances where coder 2 used *team information exchange (TIE)* instead of *team knowledge sharing (TKS)*.

Table 3. Coder Pivot Table Showing Kappa Results for the Air Operations Center Data.

CODE TITLE	ADMIN	MISC	TIE	IIG	IIS	ECSA	TKS	COA	RTA	TSOG	TENA	ITK	UR	PRTA	ECF	Total Coder 2
ADMIN	**183**	0	0	0	0	0	1	0	0	0	0	0	0	0	1	185
MISC	0	**663**	6	0	0	0	0	1	0	0	0	0	0	0	0	670
TIE	0	1	**1134**	5	9	1	24	9	0	2	0	0	0	1	1	1187
IIG	2	0	2	**521**	0	0	1	0	0	0	0	0	0	0	0	526
IIS	0	0	4	0	**23**	0	6	0	0	0	0	0	0	0	0	33
ECSA	0	0	0	0	0	**4**	0	0	0	0	0	0	0	0	0	4
TKS	0	0	17	1	6	1	**136**	3	0	3	3	1	0	1	0	172
COA	0	0	4	1	0	0	1	**138**	1	1	0	0	0	0	3	149
RTA	0	0	4	1	0	0	1	0	**78**	0	0	0	0	0	3	87
TSOG	0	0	1	0	1	2	0	0	0	**6**	1	0	0	0	0	11
TENA	0	0	0	0	0	0	0	0	0	1	**3**	0	0	0	0	4
ITK	0	0	0	0	0	0	0	0	0	0	0	**3**	0	0	0	3
UR	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0	0
PRTA	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0
ECF	0	2	20	8	33	4	39	3	2	6	5	2	1	2	**0**	127
Total Code 1	185	666	1192	537	72	12	209	154	81	19	12	6	1	4	8	3158

Table 4 presents an excerpt of individual knowledge building from the Air Operations Center dynamic targeting scenario that includes several instances of *individual information gathering*, *individual information synthesis*, and *team information exchange*.

Table 4. Individual Knowledge Building: Examples from Air Operations Center.

Individual Knowledge Building		
Originator	**Communication**	**Code**
C2DO	SIDO: I missed the name of the airfield?	IIG
C2DO	SIDO: Type of aircraft we are looking for and its latitude and longitude?	IIG
SODO	Command control duty officer (C2DO), what is the capability to track STOL Cargo aircraft with (Tac C2)?	IIG
SIDO	C2DO, STOL cargo aircraft has departed to the target; may operate between 44 and 200 knots.	IIS
IOT	NTI: What can you tell me about bomb supplier #1?	IIG
NTI	Information operations targeteer, bomb supplier #1 is a known materials supplier; communication on cover and will report any new intelligence when available.	IIS/ TIE

C2C0: Command and Control Officer SODO: Special Operations Duty Officer
SIDO: Senior Intelligence Duty Officer IOT: Information Operations Targeteer

Team Knowledge Building

Team Knowledge Building includes actions taken by team members to disseminate and transform information into actionable knowledge. To be effective in the highly dynamic environment of time-sensitive targeting, AOC team members must be ready to make rapid decisions for difficult problems in a time-compressed environment. The data indicate team members engaged in a large percentage of *information sharing* to keep all team members aware of the evolving situation. Table 5 provides examples of *team information exchange* where team members discussed the effects of radiological fallout from a possible strike against a building. They also provided an alternate solution option – *team solution option generation* (TSOG). *Team Knowledge Building* is essential to develop and maintain team situation awareness that provides the foundation for informed decision making.

Table 5. Team Knowledge Building: Team Information Exchange Example.

Team Knowledge Building: Team Information Exchange and Solution Option Generation		
Originator	**Communication**	**Code**
DEC	Awaiting radiological impact assessment on watershed if the building is to be strike. Second option in work is to destroy local roads to prevent access in/out.	TIE TSOG
DECD	Aircraft returns watershed non-issue	TIE
SIDO	Airfield is located at (*Removed*); type of aircraft is STOL cargo plane.	TIE/TIE
JOC_JCE	Dynamic effects cell, you have high-value target on your dynamic target list. What is the air combat commander game plan? If you have a good one, I will appoint you the lead but I think SOF needs to be considered.	TIE IIG

DEC: Dynamic Effects Cell DEDC: Dynamic Effects Cell Deputy JOC_JCEE: Joint Operations Center

A total of 63.17, 59.58, and 62.29 percent, respectively, of the team communications for the AOC, NORAD, and UAV tasks, were coded as one of the macrocognitive processes that occur during the *Team Knowledge Building* Stage. Macrocognitive processes that were used by the team include *Team Information Exchange* (TIE), *Team Knowledge Sharing* (TKS), *Team Solution Option Generation* (TSOG), and *Team Evaluation and Negotiation of Alternatives* (TENA). The first entry in Table 5 provides an example of team information exchange, "Awaiting radiological impact assessment on watershed if the building is to be strike," followed by an example of *Team Solution Option Generation*, "Second option in work is to destroy local roads to prevent access in/out. Table 6 presents an excerpt from the AOC chat log data that illustrates team members sharing information on rules of engagement and discussing the effects of a strike mission against an airfield.

Table 6. Macrocognitive Processes during Team Knowledge Building Stage of Collaboration.

Team Knowledge Building		
Originator	**Communication**	**Code**
DEC	Self defense applies for hostile acts from Country #3 fighters in Country # 2 or #4 airspace.	TKS
DEC	Enemy forces that employ ordnance, electronic attack or achieve a radar lock against friendly forces have committed a hostile act	TKS
TDO	If we crater the runway and taxiways, we may be able to effectively stop the target.	TSOG
IOT	Target Duty Officer (TDO): Just throwing this out there, but if you target the roadways, is there a chance you could spook them and they might fire off their missiles and run?	TENA

DEC: Dynamic Effects Cell TDO: Target Duty Officer IOT: Information Operations Targeteer

Externalized Team Knowledge

Externalized Team Knowledge refers to knowledge that has been agreed upon by members of the team. Table 7 presents examples of the macrocognitive processes employed during the *Externalized Team Knowledge* stage from the AOC data. *Externalized Cue-Strategy Associations* (ECSA) describe the team's collective agreement as to their task strategies and the situational cues that modify those strategies (and how). An example of this is found in the first entry of Table 7, where the operator says, "The dynamic effects cell chief stated that if there is an erect launcher in a joint special operations area (JSOA) his rules of engagement (ROE) are to kill it as soon as possible and if there is time, to de-conflict with the teams." An example of *Uncertainty Resolution* (UR) is found in #6, Table 7, where the Joint Special Operations Force Targeteer says: "TLAMs most definitely have to be de-conflicted even for over flight of the JSOA, unless directed otherwise by the JFC."

Pattern Recognition and Trend Analysis (PRTA) refers to the accuracy of the patterns or trends explicitly noted by members of a team that is either agreed upon or unchallenged by other team members. A member of the dynamic effects cell provides an example of PRTA, entry #7, with the following: "Looks like this target may be similar to our first target with regards to unknown presence of radiological containers in facility. We would look at interdiction for containment to prevent travel to/from that site, your thoughts on best plan/option."

Table 7. Examples of Externalized Team Knowledge from Air Operations Center Data.

	Externalized Team Knowledge		
No.	**Originator**	**Communication**	**Code**
1.	DECSOLE	The dynamic effects cell chief stated that if there is an erect launcher in a joint Special operations area (JSOA) his rules of engagement (ROE) are to kill it as soon as possible and if there is time, to de-conflict with the teams.	ECSA
2.	JSOFT	Correct, if per joint force commander (JFC)	TIE
3.	DECSOLE	I can't remember ROE in the west for OIF but I think it was something similar.	TIE
4.	DECSOLE	He mentioned tomahawk land attack missiles (TLAM) wouldn't be de-conflicted either, but I dispute that logic. First, we wouldn't use a TLAM to shot a launcher… I don't think. Unless it was a last resort.	ECSA
5.	SECSOLE	Second the flight time is great enough to pass the warning and do the de-confliction.	TIE
6.	JSOFT	TLAMs most definitely have to be de-conflicted even for over flight of the JSOA, unless directed otherwise by the JFC. He's not the JFC. If any issues, let me know and I'll pass up to the joint special operation task force commander for discussion with the JFC.	UR/ ECSA
7.	DEC	Looks like this target may be similar to our first target with regards to unknown presence of Radiological containers in facility. We would look at interdiction for containment to prevent travel to/fm that site, your thoughts on best plan/option	PRTA

DECSOLE: Dynamic Effects Cell Special Operations Liaison Officer
JSOFT: Joint Special Operations Force Targeteer
SECSOLE: Special Operations Liaison Officer   DEC: Dynamic Effects Cell

Table 8 presents an example of how information was shared as a series of *team information exchanges (TIE)* and *individual information gathering (IIG)*. That is, requests for information were integrated and lead Huntress to decide on a major course of action, without solving the overall problem. Specifically, *Team Information Exchange* led to *Individual Information*

Gathering, which led to *Decision to Take Action (Course of Action),* "Intercept. Intercept. We want the aircraft away from there," and then the problem continues.

Table 8. Excerpt from NEADS data to illustrate the Dynamic Decision-Making Process.

Line	Speaker	Message	Code
702	*Male Speaker*:	Sergeant Demage?	MISC
		We are working a tanker.	TIE
703	*Sergeant M:*	There is a bomb on board Boston -	TIE
704	*Male Speaker*:	*Expletive*	MISC
705	*Male Speaker:*	On board what? Boston 93?	IIG
706	*Huntress*:	United.	TIE
707	*Male Speaker*:	United?	IIG
708	*Sergeant M:*	Bomb on board United 93.	TIE
709	*Huntress*:	Intercept. Intercept. We want the aircraft away from there.	DTA (COA)

DISCUSSION

A new macrocognitive process emerged during coding. *Decision to Take Action* (DTA) is considered to be both a macrocognitive *process* and a *product* (Klein, 1993). This finding indicates a non-exhaustive set of macrocognitive processes in the model of team collaboration. These results corroborate results from other analyses based on analysis and coding transcripts from other dynamic decision-making tasks (Hutchins & Kendall, in press; Hutchins & Kendall, 2008). For example, in a 30-minute air warfare scenario, nine decisions to take action were made by the air warfare team. Moreover, nineteen percent of the team communications from the Fire Department of New York responding to the Sept 11, 2001, attacks on the World Trade Center involved decisions to take action.

Coding schemes should be mutually exclusive, exhaustive, and equivalent. The high Cohen Kappa coefficient indicates the two coder's agreement is substantial and indicates the macrocognitive process definitions are objective. The pivot table of results highlights instances where the two coders disagreed and shows which codes were used by the other coder when there were disagreements. Disagreements indicate macrocognitive processes that are not mutually exclusive. Definitions for some macrocognitive processes may need to be refined to remove ambiguity.

Planning tasks can also trigger decisions to take action. One example involves flight planning by an air crew. The crew may have a discussion regarding the weather and then arrive at a DTA in the form of deciding to change the route, altitude, amount of fuel, or even the destination. These are critical decisions as a wrong decision could have an unfavorable outcome. Moreover, these decisions are sometimes modified over the course of the flight as new information is gathered and evaluated. In the UAV example reported in the results section, there were several DTAs.

At this time our working hypothesis is the more a task or problem entails dynamic decision making the higher the number of DTAs will be required. We plan to test this hypothesis with analysis of additional tasks from several decision-making and planning task domains. We anticipate planning tasks will entail less DTAs; one reason is that planning does not include tasks that require dynamic decisions – unless the task entails dynamic planning/re-planning while executing the task. The traditional planning process, where planning for the task is performed

prior to execution, is somewhat static in that the situation does not change. A planning task generally entails a finite set of decisions in contrast to the many emergent decisions that arise in dynamic decision-making situations. The state of the world changes during dynamic decision-making situations but not during planning and perhaps this is the biggest difference between planning and execution. During execution tasks decisions are made in real time and must be made in the correct moment in time, whereas time is not really a factor in planning.

CONCLUSIONS

Decision to Take Action is recommended as a new category to be added to the set of macrocognitive processes included in the Fiore, Smith-Jentsch, Salas, Warner, and Letsky (in press) model of team collaboration. Deciding to take action is viewed as both a macrocognitive *process* and a *product* of team collaboration. We maintain that decision making is a critical element of team problem solving when a team is executing a task, and to a lesser degree when conducting a planning task. When team members collaborate to solve a problem they make decisions and implement those decisions as part of performing the task. Team communications often entail asking or telling a team member to perform some action that will move the problem further along toward completion. This contrasts with a team who is collaborating on a planning task, where deciding on and implementing decisions may not be evident. This is the case for problem-solving domains in the military, government, and the private sectors. For example, we predict this same pattern would be evident for a surgical team, a humanitarian assistance scenario, a process control system for an energy plant, and a variety of other task domains.

Decision Making is Part of Problem-Solving

Many critical tasks that involve team problem solving include decision making; that is, team members take action in addition to developing new knowledge and agreeing on a final solution. Actions are frequently part of the overall information gathering process and have diagnostic functions (Orasanu & Connolly, 1993; Orasanu & Fischer, 1997). For the task domains discussed here, a constant interplay exists between sharing information – to develop new knowledge and maintain situation awareness – and deciding on actions, and implementing these actions, followed by monitoring the situation and continuing to build new knowledge on the unfolding situation. Execution of the mission, or problem-solving task, would come to a screeching halt without this continual, iterative cycle of developing knowledge of the situation and responding to the current situation.

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REFERENCES

Air Force Research Laboratory Warfighter Readiness Division. (2008). Training Exercise 09-1: Trainee Preparation Reader.

Burke, C. S. (2007). Panel Discussion on Macrocognition. 8th International Conference on Naturalistic Decision Making. Asilomar, CA.

Fiore, S. M., Smith-Jentsch, K. A., Salas, E., Warner, N., & Letsky, M. (in press). Toward an Understanding of Macrocognition in Teams: Developing and Defining Complex Collaborative Processes and Products. *Theoretical Issues in Ergonomic Science.*

Fischer, U., Orasanu, J., & Montalvo, M. (1993). Efficient decision strategies on the flight deck. In R. Jensen (Ed). *Proceedings of the 7th Symposium on Aviation Psychology* (pp. 238-243), Columbus, OH: Ohio State University.

Hutchins, S. G., and Kendall, A. (2008). *Patterns of Team Collaboration Employed to Solve Complex Problems*. In *Proceedings of the 52nd Annual Meeting of the Human Factors and Ergonomics Society*, New York, September 22-26. Santa Monica, CA.

Hutchins, S. G., and Kendall, T. (in press). The Role of Cognition in Team Collaboration during Complex Problem Solving. To appear in K. L. Mosier and U. M. Fischer (Eds.), *Informed by Knowledge: Expert Performance in Complex Situations.* Taylor and Francis.

Katzenbach, J. R., & Smith, D. K. (1993). Reengineering the corporation. New York: Harper Collins Publishers.

Klein, G. A. (1989). Recognition-primed decisions. In W. R. Rouse (Ed.) *Advances in man-machine systems research* (Vol. 5, pp. 47-92). Greenwich, CT: JAI Press.

Klein, G. (1993). Sources of error in naturalistic decision making tasks. In *Proceedings of the 37th Annual Meeting of the Human Factors and Ergonomics Society*, pp. 368-371. Santa Monica, CA: Human Factors and Ergonomics Society.

Klein, G., Phillips, J. K., Rall, E. L., & Peluso, D. A. (2007). A data-frame theory of sensemaking. In R. Hoffman (Ed.), *Expertise out of context* (pp. 113-155). New York, NY: Lawrence Erlbaum Associates.

Klein, G., Ross, K. G., Moon, B. M., Klein, D. E., Hoffman, R. R., & Hollnagel, E. (2003). Macrocognition. *IEEE Intelligent Systems*, *18*(3), 81-85.

Klein, G., Snowdon, D., & Pin, C. L. (2007). Anticipatory Thinking. Proceedings of the 8th International NDM Conference. (Ed.s K. Mosier & U. Fischer), Pacific Grove, CA, June 2007.

Letsky, M., & Warner, N. (2008). Macrocognition in teams. In M. Letsky, N. Warner, S. M. Fiore, & C. Smith (Eds.). *Macrocognition in Teams* (pp. 1-13). London: Ashgate.

Letsky, M., Warner, N., Fiore, S. M., Rosen, M., & Salas, E. (2007, June). Macrocognition in complex team problem solving. In *Proceedings of the 12th International Command and Control Research & Technology Symposium*, Newport, RI.

Memorandum of understanding between NORAD and the FAA. (1987). HQ North American Aerospace Defense Command Regulation 55-18. Peterson Air Force Base, Colorado 80914-5001 23. November, 1987.

Montgomery, H. (1983). Decision rules and the search for a dominance structure: Towards a process mode of decision making. In P. Humphreys, O. Svenson, & A. Vari (Eds.), *Analyzing and aiding decision processes* (pp. 343-369). Amsterdam: North-Holland.

Montgomery, H. (1989). From cognition to action: The search for dominance in decision making. In H. Montgomery, & O. Svenson. (Eds.), *Process and structure in human decision making* (pp. 23-49). Chichester, England: Wiley.

Mosier, K. L. (1991). Expert decision making strategies. In R. Jensen (ed.), *Proceedings of the Sixth International Symposium on Aviation Psychology* (pp. 266-271). Columbus, OH: Ohio State University.

Nosek, J. T. (2004). Group cognition as a basis for supporting group knowledge creation and sharing. *Journal of Knowledge Management*, *8*(4), 3-18.

Orasanu, J. M. (1994). Shared problem models and flight crew performance. N. Johnston, N. McDonald, & R. Fuller (Eds.), *Aviation psychology in practice* (pp. 1-22). Aldershot, England: Ashgate.

Orasanu, J., & Connolly, T. (1993). The reinvention of decision making. In G. A. Klein, J. Orasanu, R. Calderwood, & C. E. Zsambok (Eds.), *Decision making in action: Models and methods* (pp. 3-20). Norwood, NJ: Ablex.

Raytheon Company (2008). *JADOCS Manual. JADOCS Overview.* Alexandria, VA

Salas, E., & Fiore, S. M. (2004). *Team cognition: Understanding the factors that drive process and performance*. Washington, DC: American Psychological Association.

Thomas, J., and Hersen, M. (2003). Understanding Research in Clinical and Counseling Psychology. Lawrence Erlbaum: Lawrence Erlbaum Associates.

Warner, N., & Letsky, M., (2008). Empirical model of team collaboration focus on macro-cognition. In M. Letsky, N. Warner, S. Fiore, C. Smith, (Eds.) *Macrocognition in teams* (pp. 15-33). London: Ashgate.

Warner, N., Letsky, M., & Cowen, M. (2005). Cognitive model of team collaboration: Macro-cognitive focus. In *Proceedings of the 49th Human Factors and Ergonomics Society Annual Meeting* (pp. 269-273). Santa Monica, CA: Human Factors and Ergonomics Society.

Wood, D. J., & Gray, B. (1991). Toward a comprehensive theory of collaboration. *Journal of Applied Behavioral Science*, 27, 149-162.